DELPHI Collaboration DELPHI 2005-018-CONF-738
30 March, 2005

Single particle inclusive production in two-photon collisions at LEP II with the DELPHI detector

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Abstract

We present a study of inclusive charged hadron production in two-photon collisions. The data were collected with the DELPHI detector at LEP II. Results on the inclusive single particle p_T spectrum and the differential charged hadrons $d\sigma/dp_T$ cross-section are presented, compared to the predictions of the perturbative NLO QCD calculations and to published results.

Contributed Paper for LP 2005 (Uppsala) and HEP-EPS 2005 (Lisbon)

1 Introduction

The inclusive production of hadrons in $\gamma^*\gamma^*$ interactions can be used to study the structure of two-photon collisions. At LEPII these collisions are the main source of hadron production, thus providing a good opportunity for such an investigation.

In this paper we present a study of the inclusive production of charged hadrons in collisions of quasi-real photons. These photons have a mass $Q^2 \sim 0$ and are radiated by beam electrons which scattered at very small angles and were not detected.

This analysis allows to check the predictions of leading and next-to-leading order (NLO) perturbative QCD computations.

Section 2 describes the selection criteria for the event sample collected for this study. The inclusive single particle transverse momentum spectrum and the differential charged hadrons cross-section are presented in Section 3 and compared to theoretical predictions and published results.

2 Experimental procedure

The analysis presented here is based on the data taken with the DELPHI detector [1, 2] in 1996-2000, covering a range of centre-of-mass energies from 161 GeV to 209 GeV (average centre-of-mass energy: 198.6 GeV). The selected data set corresponds to the period when the Time Projection Chamber (TPC) was fully operational thus ensuring good particle reconstruction. The corresponding integral luminosity used in this analysis is 617 pb^{-1}.

The charged particle tracks were measured in the 1.2 T magnetic field by a set of tracking detectors including the microVertex Detector(VD), the Inner detector (ID), the TPC, the Outer Detector(OD) and the Forward/Backward Chambers FCA and FCB. The following selection criteria are applied:

- transverse particle momentum $p_T > 150$ MeV/c;
- impact parameter of a track transverse to the beam axis $\Delta_{xy} < 0.4$ cm;
- impact parameter of a track along the beam axis $\Delta_z < 2$ cm;
- polar angle of a track $10^\circ < \theta < 170^\circ$;
- track length $l > 30$ cm;
- relative error of the track momentum $\Delta p/p < 100\%$.

The measurement of neutral particles is made using calorimeter information. The calorimeter clusters, which are not associated to charged particle tracks, are combined to form the signals from the neutral particles (γ, π^0, K^0_L, n). The following thresholds were set on the measured energy: .5 GeV for showers in the electromagnetic calorimeters and 2 GeV for showers in the hadron calorimeters.

To extract the hadronic two-photon events the following cuts are applied:

- energy deposited in the DELPHI luminometer (STIC: $2.5^\circ < \theta_{STIC} < 9^\circ$): $E_{STIC} <30$ GeV;
- number of charged tracks $N_{ch} > 4$;

- visible invariant mass, calculated from the four-momentum vectors of the measured charged and neutral tracks: 5 GeV/c^2< W_{vis} <35 GeV/c^2.

The first condition eliminates the so-called single and double-tagged $\gamma^*\gamma^*$ events. The condition on the charged track muliplicity as well as the lower limit on W_{vis} reduce the background from $\gamma^*\gamma^* \to \tau^+\tau^-$ and $e^+e^- \to \tau^+\tau^-$ events. The upper limit on W_{vis} cuts down the background from $e^+e^- \to q\bar{q}(\gamma)$ and four-fermion processes.

The comparison of the W_{vis} distributions (Fig. 1) for the data and the Monte Carlo (MC) generated sample described in the following section illustrates the effects of the W_{vis} cuts.

About 910k events were selected after application of the above cuts.

To guarantee a good measurement of the tranverse momentum, only charged tracks in the pseudorapidity intervals $|\eta|$ <1 (40.4° < θ_{ch} < 139.6°) and $|\eta|$ <1.5 (25.2° < θ_{ch} < 154.8°) were used in our study.

3 Data Analysis and Results

The p_T spectrum of the charged particles of the selected events is presented in Fig.2 together with the expected Monte Carlo generated contributions, normalized to the data integral luminosity.

For the generation of $\gamma^*\gamma^* \to$ *hadrons* events the PYTHIA 6.143 program [3] was used. The main background coming from inclusive $e^+e^- \to q\bar{q}(\gamma)$ channels has also been estimated from a PYTHIA MC sample. The simulations of the $e^+e^- \to$ four-fermion, the $\gamma^*\gamma^* \to \tau^+\tau^-$ and the $e^+e^- \to \tau^+\tau^-$ backgrounds were based on the EXALIBUR, BDKRS and KORALZ 4.2 generators, respectively. The Monte Carlo generated events were then passed through the detector simulation and reconstruction programs. The same cuts were applied on the reconstructed events as on the data.

Fig.2 shows that the data are well reproduced by the simulated sample of events and that the $e^+e^- \to q\bar{q}(\gamma)$ channel is the main contributor for p_T >12 GeV/c.

The ratio of the data versus Monte Carlo p_T spectra is presented in Fig.3. One verifies that the data distribution is consistent with the Monte Carlo simulation for p_T > 2 GeV/c. The lack of data at p_T <2 GeV/c can be explained by the trigger efficiency which was not accounted for in the Monte Carlo simulation and is low for low p_T tracks.

The L3 experiment has performed a similar analysis [4] and has observed that the p_T spectrum of charged particles considerably exceeds NLO QCD predictions at high p_T values. In order to check this result on our data we have repeated our analysis adopting the "L3-like" set of selection criteria. The main difference is that our cut on W_{vis} <35 GeV/c^2 is replaced by a cut on the normalized visible energy $E_{vis}/\sqrt{s}$ < .4, $\sqrt{s}$ being the total centre of mass energy of e^+e^- collisions. For a mean energy $\sqrt{s}$ ∼ 190 GeV this is equivalent to a E_{vis} <76 GeV upper limit. We also changed our threshold of 4, for the number of charged particle tracks to 6 for the total number of particles (including neutrals) as chosen by L3.

The p_T spectrum of charged particles for the "L3-like" events is presented in Fig.4 together with the contributing channels. One sees that the p_T distribution at high values of p_T (p_T >6 GeV/c), is dominated by the $e^+e^- \to q\bar{q}(\gamma)$ background channel. Although this contamination is quantitatively low ∼.6% of the events, it is concentrated in the high

p_T region. (With our W_{vis} <35 GeV/c^2 cut, it is of $\sim$ .1% of the events only). This can explain the anomalous behaviour of the p_T spectrum observed by L3 [4]. On the other hand L3 has used a differenf generator, KK2f, to estimate the $e^+e^- \rightarrow q\bar{q}(\gamma)$ channel contribution.

The differential inclusive charged hadrons $d\sigma/dp_T$ cross-section distribution has been obtained by subtracting the background contributions from the experimental dN/dp_T data. The resulting distribution has been applied, bin-by-bin, a correction factor which is the ratio of the numbers of generated and reconstructed Monte Carlo events.

Table 1 gives the values of $d\sigma/dp_T$ as a function of p_T for $|\eta|$ <1 and $|\eta|$ <1.5 and for p_T >1.6 GeV/c which corresponds to an event trigger efficiency close to 100%.

The measured $d\sigma/dp_T$ are compared with the NLO QCD prediction [5] in Fig.5. One sees some excess of data for p_T >6 GeV/c but not at the level of L3. Below 6 GeV/c, the data follow well the NLO QCD prediction, as observed by OPAL [6]. On the other hand the data are in very good agreement with PYTHIA (see Fig.3) over the whole p_T range, as already noticed above.

4 Conclusions

The study of the inclusive charged hadron production in two-photon collisions has been carried out at the DELPHI detector at LEP II. Results are reported: the inclusive single particle p_T spectrum has been extracted and the differential inclusive $d\sigma/dp_T$ cross-section has been measured.

The differential inclusive $d\sigma/dp_T$ cross-sections are found to be comptable with the NLO QCD predictions.

Acknowledgements

We are greatly indebted to our technical collaborators and to the funding agencies for their support in building and operating the DELPHI detector, and to the members of the CERN SL Division for the excellent performance of the LEP collider.

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p_T, GeV/c	$d\sigma/dp_T$, pb/GeV/c	
	$\lvert\eta\rvert < 1$	$\lvert\eta\rvert < 1.5$
1.6 - 2.0.	229.2±1.6±7.0	287.6±1.8±12.1
2.0 - 2.4	87.8±1.0±2.0	111.4±1.1±4.6
2.4 - 2.8	39.6±0.7±0.8	50.4±0.7±0.8
2.8 - 3.2	20.7±0.5±0.4	26.0 ±0.5±0.6
3.2 - 3.6	12.6±0.4±0.3	16.0±0.4±0.1
3.6 - 4.0	7.4±0.33±0.21	9.3± 0.3±0.15
4.0 - 4.4	4.5±0.25±0.20	5.7±0.27±0.21
4.4 - 4.8	2.7±0.21±0.26	3.9±0.22±0.03
4.8 - 5.2	2.2±0.17±0.11	2.8±0.19±0.03
5.2 - 5.6	1.34±0.16±0.04	1.66±0.14±0.0.2
5.6 - 6.0	1.32±0.14±0.05	1.68±0.16±0.12
6.0 - 6.4	0.98±0.12±0.02	1.16±0.12±0.02
6.4 - 6.8	0.49±0.09±0.04	0.79±0.12±0.05
6.8 - 7.2	0.67±0.11±0.14	0.74±0.11±0.07
7.2 - 7.6	0.42±0.09±0.02	0.51±0.09±0.04
7.6 - 8.0	0.31±0.08±0.02	0.36±0.07±0.01
8.0 - 9.0	0.24±0.06±0.08	0.32±0.07±0.06
9.0 - 10.0	0.15±0.05±0.06	0.23±0.08±0.06
10.0 - 12.0	0.10±0.03±0.05	0.12±0.03±0.06
12.0 - 14.0	0.05±0.03±0.05	0.05±0.01±0.03
14.0 - 16.0	0.04±0.03±0.03	0.05±0.02±0.03

Table 1: Differential inclusive $d\sigma/dp_T$ for charged particles in $\gamma\gamma$ collisions for $|\eta|$ <1 and $|\eta|$ <1.5 and 5 GeV/c^2< $W_{\gamma\gamma}$ <203 GeV/c^2. The first error is statistical, the second is the systematic uncertainty

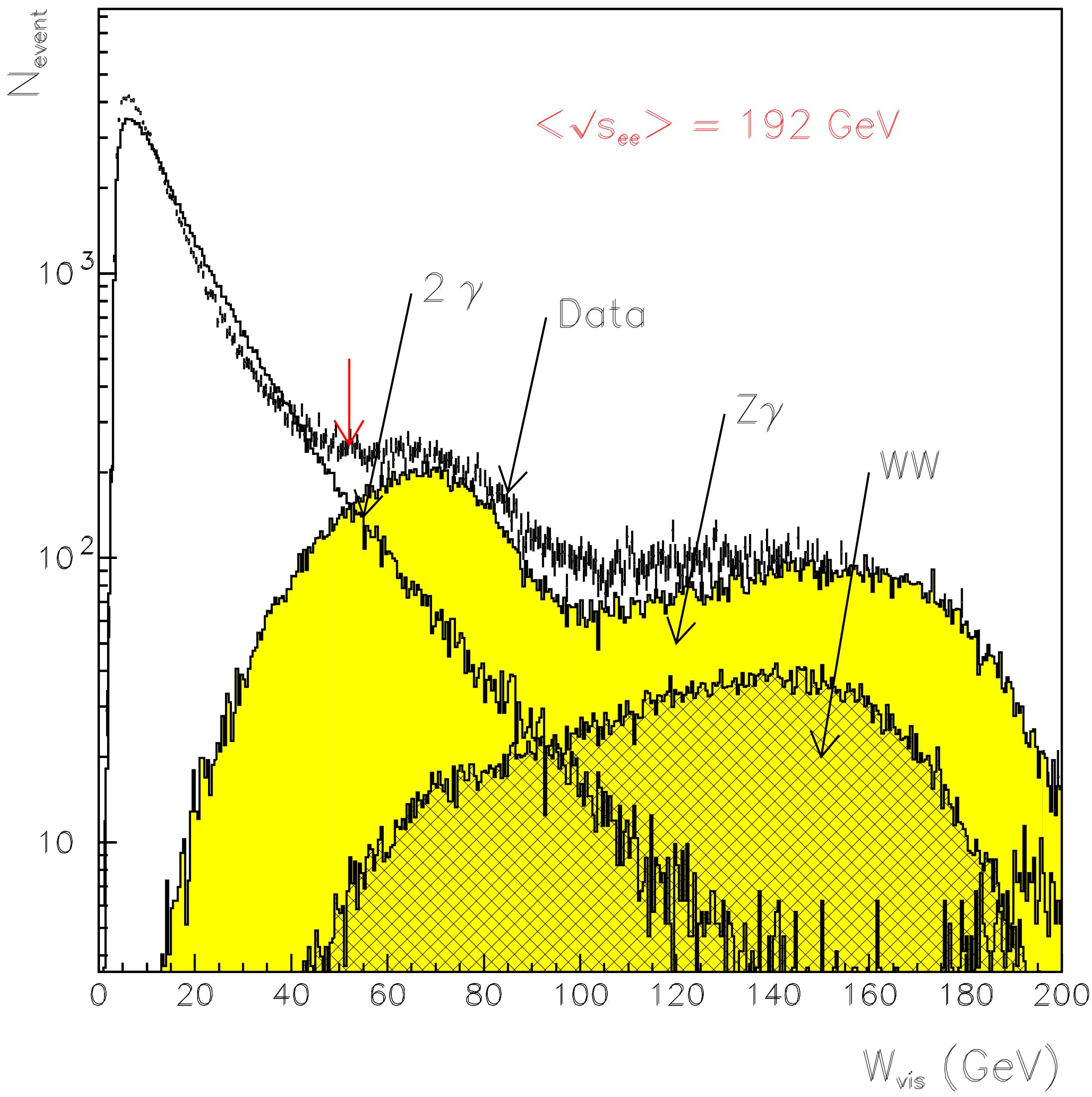

Figure 1: W_{vis} distributions for the data at $<\sqrt{s_{\rm ee}}>= 192$ GeV and for the simulated $\gamma\gamma\rightarrow$ *hadrons*, $\mathrm{e^+e^-} \rightarrow \mathrm{Z^0}\gamma$ and $\mathrm{e^+e^-} \rightarrow \mathrm{W^+W^-}$ events at $\sqrt{s_{\rm ee}} = 200$ GeV

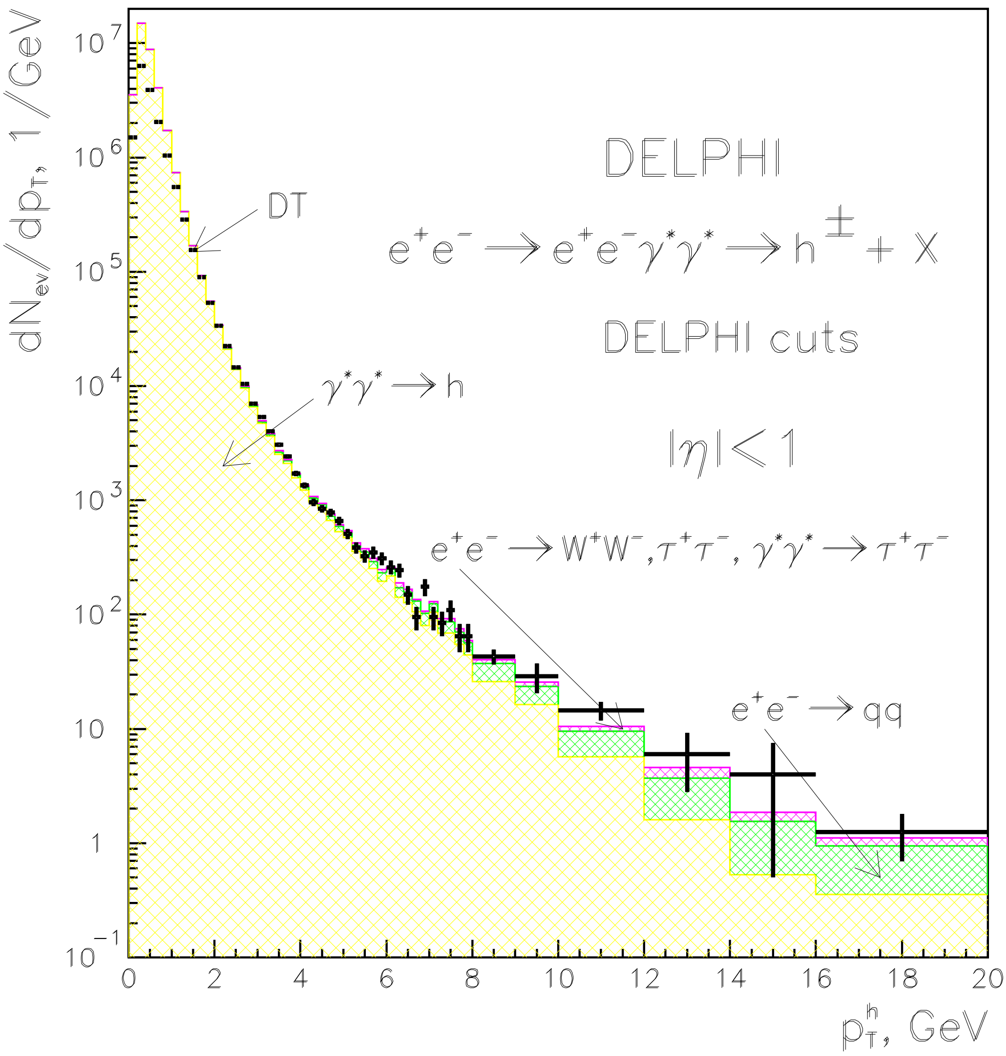

Figure 2: p_T spectrum of charged particles produced in $\gamma\gamma$ collisions, for $|\eta| <1$..

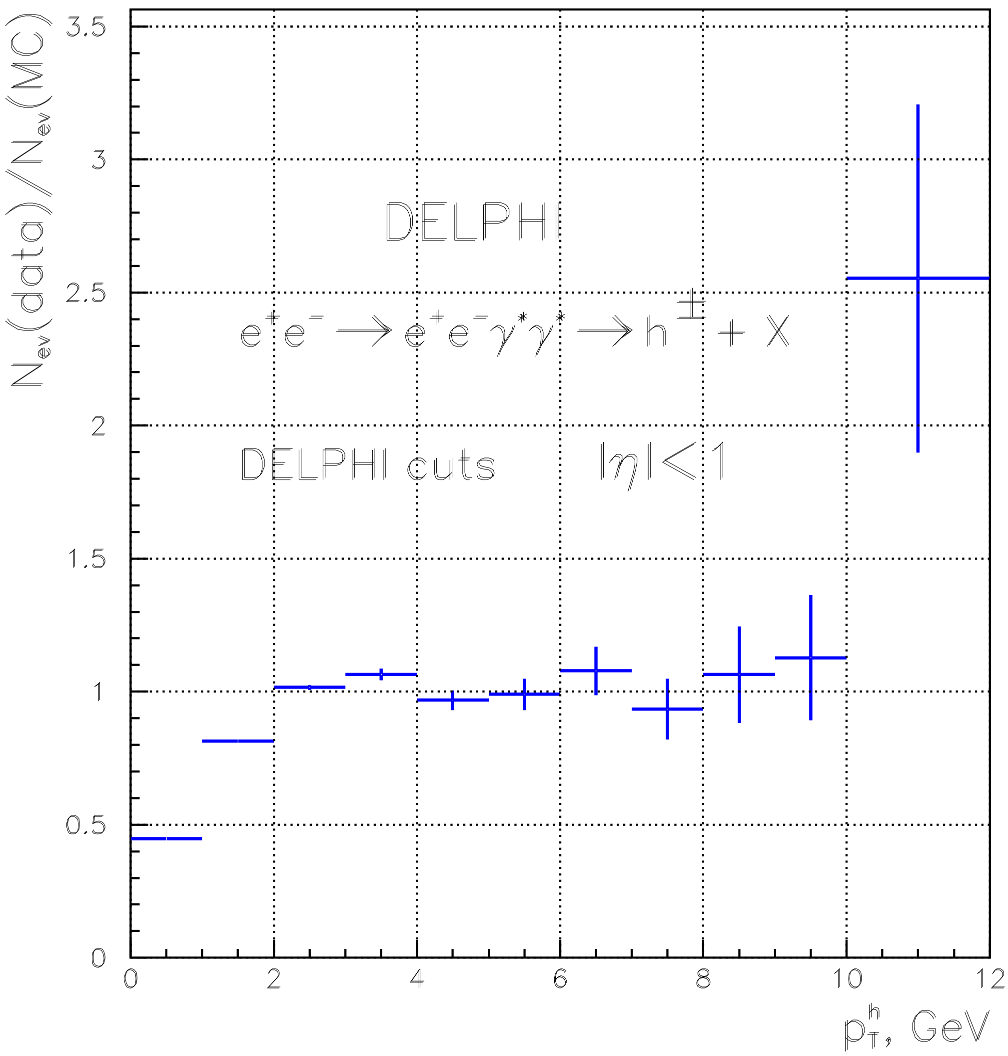

Figure 3: Ratio of charged particles data and Monte Carlo p_T spectra.

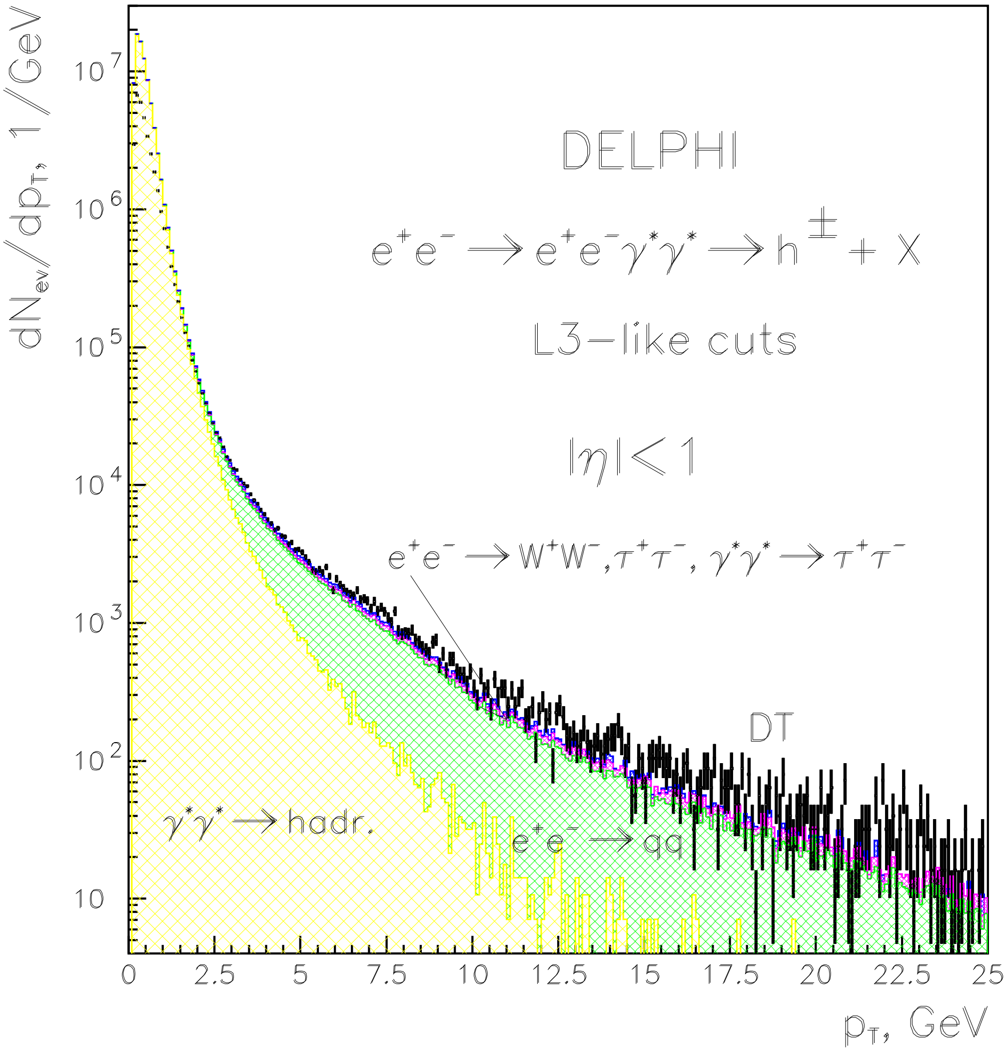

Figure 4: p_T spectrum of charged particles applying the "L3-like" selection criteria and MC generated contributing processes.

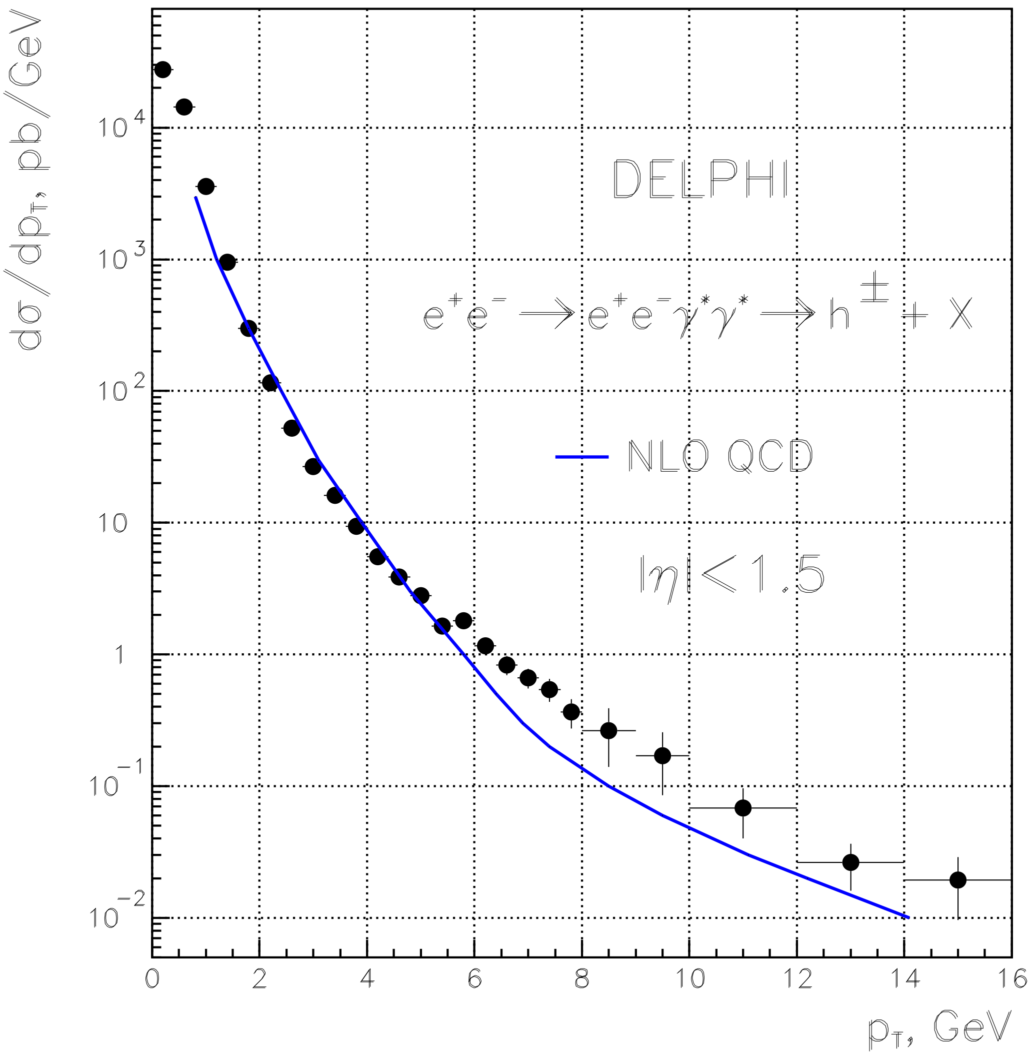

Figure 5: Differential inclusive $d\sigma/dp_T$ spectrum for charged particles produced in $\gamma\gamma$ collisions for $|\eta|$ <1.5 and corresponding NLO QCD prediction.